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4. TITLE AND SUBTITLE Final Report: Nonlinear and Probabilistic Analysis with Frames			5a. CONTRACT NUMBER W911NF-16-1-0008		
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			5c. PROGRAM ELEMENT NUMBER 611102		
6. AUTHORS			5d. PROJECT NUMBER		
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7. PERFORMING ORGANIZATION NAMES AND ADDRESSES University of Maryland - College Park Office of Research Administration 3112 Lee Building 7809 Regents Drive College Park, MD 20742 -5141			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211			10. SPONSOR/MONITOR'S ACRONYM(S) ARO		
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13. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Radu Balan
a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU			19b. TELEPHONE NUMBER 301-405-5492

RPPR Final Report

as of 20-Feb-2019

Agency Code:

Proposal Number: 68099MA

Agreement Number: W911NF-16-1-0008

INVESTIGATOR(S):

Name: Radu Balan

Email: rvbalan@math.umd.edu

Phone Number: 3014055492

Principal: Y

Organization: **University of Maryland - College Park**

Address: Office of Research Administration, College Park, MD 207425141

Country: USA

DUNS Number: 790934285

EIN: 526002033

Report Date: 08-Feb-2019

Date Received: 15-Feb-2019

Final Report for Period Beginning 09-Nov-2015 and Ending 08-Nov-2018

Title: Nonlinear and Probabilistic Analysis with Frames

Begin Performance Period: 09-Nov-2015

End Performance Period: 08-Nov-2018

Report Term: 0-Other

Submitted By: Radu Balan

Email: rvbalan@math.umd.edu

Phone: (301) 405-5492

Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 1

STEM Participants: 5

Major Goals: This proposal presents three problems in frame theory inspired by quantum theory and quantum information processing: robust quantum state detection and estimation; optimal quantum frames, and redundant quantum representations and dimension reduction.

Recent progress on fundamental topics of frame theory (e.g., Kadison-Singer problem, the Paulson problem) show the far-reaching power of frame analysis. The authors of this proposal believe the time is right for a breakthrough in any and all of the three problems presented here.

Given a positive-valued measure, the quantum detection and estimation problem asks to robustly identify a quantum state from a set of quantum measurements. One tool to answer this question is provided by probabilistic frames, which yields an optimization problem in quantum frames. The third problem is related to quantum graphs, and quantum dimension reduction that together offer a new type of redundant representation.

Accomplishments: The PI, co-PIs, and other personnel have a total of over 18 invited talks and presentations. 32 refereed papers and book chapters have been submitted for publication or have been accepted. One postdoctoral associate (at the University of Maryland) and one graduate student (at the University of Missouri) have been mentored, and one graduate student (at the University of Missouri) has defended his thesis and graduated.

The postdoctoral associate at UMD has received and accepted an offer of tenure-track assistant professorship at the Iowa State University (Fall 2018).

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Training Opportunities: The grant provided support for one postdoctoral associate (Joey Iverson) and three graduate students (David Bekkerman, Naveed Haghani and Chris Dock) at the University of Maryland. The grant also provided support for two graduate students (Tin Tran and Desai Cheng) both at the University of Missouri.

Joey Iverson has received and accepted a tenure-track position at the Iowa State University (Fall 2018). Desai Cheng graduated in May 2018.

The PI and co-PIs organized Research Interaction Teams (RIT) at the University of Maryland. These are weekly internal seminars/presentations by our team members:

Spring and Summer 2016: Quantum Information Systems

Fall 2016 - Fall 2018: Applied Harmonic Analysis

Close collaboration with Radhakrishnan Balu (ARL, Adelphi) during this time.

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Results Dissemination: In addition to the papers described below, the PI and co-PIs delivered several talks and lectures as follows:

Radu Balan:

- * June 2018: Conference on Time-Frequency Analysis, University of Hasselt and Molenheide, Belgium.
- * May 2018: Invited Plenary Talk, ICCHA 2018, Vanderbilt University, Nashville, TN
- * March 2018: Oberwolfach Workshop, Oberwolfach, Germany.
- * September 2017: AMS Conference, University of Central Florida, Orlando, FL
- * Invited short talk at AMS special session on Frames and Sampling at JMM Atlanta 2017, January.
- * Invited short talk at AMS special session on Signal Processing at JMM Atlanta 2017, January.

John Benedetto:

- * May 2018: talk at ICCHA 2018, Vanderbilt University, Nashville, TN.
- * Fall 2017, Data Analysis Seminar at Johns Hopkins University, Baltimore, MD;
- * August 2017: Plenary talk at CIMPA, Buenos Aires, Argentina.
- * Invited short talk at AMS special session on Frames and Sampling at JMM Atlanta 2017-01.
- * Invited short talk at AMS special session on Signal Processing at JMM Atlanta 2017-01.

Pete Casazza:

- * May 2018: talk at ICCHA 2018, Vanderbilt University, Nashville, TN.
- * Spring 2018: Three lectures at the Louisiana State University, Baton Rouge, LA
- * Invited short talk at AMS special session on Frames and Sampling at JMM Atlanta 2017, January.
- * BIRS Mexico, Oct. 2016.
- * September 2016: AMS Sectional Meetings on Topological Phases of Matter and Quantum Computation, Bowdoin College, Brunswick.
- * Talk in special session Applied Harmonic Analysis and frame theory at the biannual IWATA, Wash.U., St. Louis, MO, July 2016.

Wojtek Czaja:

- * Invited talk at Time-Frequency Analysis and Related Topics Conference, Strobl, Austria, June 9, 2016
- * Invited talk at DTRA Basic Research Technical Review, Springfield, VA, July 18, 2016
- * Invited talk at SIAM Conference on Computational Science and Engineering, Atlanta GA, February 27, 2017

Joey Iverson:

- * April 2018: Special Session on Harmonic Analysis, Functional Analysis, and Their Applications, Vanderbilt University, Nashville, TN.
- * February 2018: Iowa State University, Ames, IA. Special Colloquium.
- * August 2017: Georgia Institute of Technology, Atlanta, GA. Analysis Seminar.
- * AMS Spring Eastern Sectional Meeting, Special Session on Bases in Hilbert Function Spaces, May 2017.
- * AMS Spring Southeastern Sectional Meeting. Special Session on Frame Theory, March 2017.

Kasso Okoudjou:

- * July 2018: 24th Conference for African American Researchers in the Mathematical Sciences (CAARMS 24), Institute of Advanced Studies, Princeton, NJ
- * May 2018: talk at the International Conference on Computational Harmonic Analysis (ICCHA), Vanderbilt University, Nashville, TN
- * March 2018: AMS Special Session on Recent Advances in Packing, Ohio State University, Columbus, OH
- * March 2018: International Conference on Technology, Engineering and Mathematics (TEM'18), Kenitra, Morocco.
- * February 2018: Workshop on "Tight frames and Approximation", Taipa, Doubtless Bay, New Zealand
- * October 2017: Series of lectures on Applied Harmonic Analysis at the African Institute of Mathematical Sciences (AIMS-South-Africa), Cape Town, South Africa.
- * AMS Special Session on Frame Theory, College of Charleston, March 2017.
- * AMS Special Session on Bases in Function Spaces: Sampling, Interpolation, Expansions and Approximations, JMM, Atlanta, January 2017.
- * QCrypt 2016 Conference (joint with Rad Balu & Paul Koprowski)

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Honors and Awards: John Benedetto was elected SIAM Fellow class of 2016.

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI

Participant: Radu Balan

Person Months Worked: 1.00

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Funding Support:

Participant Type: Co PD/PI

Participant: Kasso Okoudjou

Person Months Worked: 1.00

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Funding Support:

Participant Type: Co PD/PI

Participant: John Benedetto

Person Months Worked: 1.00

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Funding Support:

Participant Type: Co PD/PI

Participant: Pete Casazza

Person Months Worked: 1.00

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Funding Support:

Participant Type: Co PD/PI

Participant: Wojtek Czaja

Person Months Worked: 1.00

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Funding Support:

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Participant Type: Postdoctoral (scholar, fellow or other postdoctoral position)

Participant: Joey Iverson

Person Months Worked: 9.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Desai Cheng

Person Months Worked: 6.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Tin Tran

Person Months Worked: 6.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: David Bekkerman

Person Months Worked: 6.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Naveed Haghani

Person Months Worked: 6.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Chris Dock

Person Months Worked: 3.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

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ARTICLES:

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Linear Algebra and Applications

Publication Identifier Type:

Publication Identifier:

Volume: 532

Issue:

First Page #: 198

Date Submitted: 8/8/17 12:00AM

Date Published:

Publication Location:

Article Title: Duality and geodesics for probabilistic frames

Authors: Clare Wickman, Kasso Okoudjou

Keywords: probabilistic frames, Wasserstein metric, duality

Abstract: Probabilistic frames are a generalization of finite frames into the Wasserstein space of probability measures with finite second moment. We introduce new probabilistic definitions of duality, analysis, and synthesis and investigate their properties. In particular, we formulate a theory of transport duals for probabilistic frames and prove certain properties of this class. We also investigate paths of probabilistic frames, identifying conditions under which geodesic paths between two such measures are themselves probabilistic frames. In the discrete case this is related to ranks of convex combinations of matrices, while in the continuous case this is related to the continuity of the optimal transport plan.

Distribution Statement: 1-Approved for public release; distribution is unlimited.

Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: N **Publication Status:** 0-Other

Journal: Arxiv: 1709.03558

Publication Identifier Type:

Publication Identifier:

Volume:

Issue:

First Page #:

Date Submitted:

Date Published:

Publication Location:

Article Title: Optimal line packings from finite group actions

Authors: J. W. Iverson, J. Jasper, D. G. Mixon

Keywords: optimal packing, finite groups

Abstract: We provide a general program for finding nice arrangements of points in real or complex projective space from transitive actions of finite groups. In many cases, these arrangements are optimal in the sense of maximizing the minimum distance. We introduce our program in terms of general Schurian association schemes before focusing on the special case of Gelfand pairs. Notably, our program unifies a variety of existing packings with heretofore disparate constructions. In addition, we leverage our program to construct the first known infinite family of equiangular lines with Heisenberg symmetry.

Distribution Statement: 1-Approved for public release; distribution is unlimited.

Acknowledged Federal Support: Y

RPPR Final Report as of 20-Feb-2019

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Linear Algebra and Applications

Publication Identifier Type: Publication Identifier:

Volume: 523 Issue: First Page #: 152

Date Submitted: Date Published: 9/1/17 4:00AM

Publication Location:

Article Title: Frame Scalings: A Condition Number Approach

Authors: P.G. Casazza, X. chen

Keywords: frames, condition number

Abstract: Scaling frame vectors is a simple and noninvasive way to construct tight frames. However, not all frames can be modified to tight frames in this fashion, so in this case we explore the problem of finding the best conditioned frame by scaling, which is crucial for applications like signal processing. We conclude that this problem is equivalent to solving a convex optimization problem involving the operator norm, which is unconventional since this problem was only studied in the perspective of Frobenius norm before. We also further study the Frobenius norm case in relation to the condition number of the frame operator, and the convexity of optimal scalings.

Distribution Statement: 1-Approved for public release; distribution is unlimited.

Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: N **Publication Status:** 5-Submitted

Journal: Arxiv: 1806.05614

Publication Identifier Type: Publication Identifier:

Volume: Issue: First Page #:

Date Submitted: Date Published:

Publication Location:

Article Title: On the Frame Set for the 2-Spline

Authors: A.G.D. Atindehou, Y.B. Kouagou, K.A. Okoudjou

Keywords: frames, splines

Abstract: The frame set of a function $g \in L^2(\mathbb{R})$ is the subset of all parameters $(a, b) \in \mathbb{R}^2$ for which the time-frequency shifts of g along $a\mathbb{Z} \times b\mathbb{Z}$ form a Gabor frame for $L^2(\mathbb{R})$. In this paper, we consider the case where $g = B_2$ is the 2-spline and prove that its frame set contains new points. We obtain this result by constructing a (unique) compactly supported and bounded dual window for B_2 for each of the parameters we consider. Incidentally, this dual is discontinuous, and thus does not belong to the Feichtinger algebra $M_1(\mathbb{R})$ in contrast to B_2 and its canonical dual.

Distribution Statement: 1-Approved for public release; distribution is unlimited.

Acknowledged Federal Support: Y

CONFERENCE PAPERS:

Publication Type: Conference Paper or Presentation **Publication Status:** 2-Awaiting Publication

Conference Name: 13th International Symposium on Bioinformatics Research and Applications (ISBRA), 2017

Date Received: 08-Aug-2017 Conference Date: 30-May-2017 Date Published:

Conference Location: Honolulu, Hawaii

Paper Title: Heterogeneous Cancer Cell Line Data Fusion for Identifying Novel Response Determinants in Precision Medicine

Authors: Wojciech Czaja, Jeremiah Emidih

Acknowledged Federal Support: Y

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as of 20-Feb-2019

Publication Type: Conference Paper or Presentation

Publication Status: 1-Published

Conference Name: Sampling Theory and Applications (SampTA)

Date Received: 08-Aug-2017 Conference Date: 01-Jun-2017

Date Published: 08-Aug-2017

Conference Location: Vilnius, Estonia

Paper Title: On the structures of Grassmannian frames

Authors: Pete Casazza, John Haas,

Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation

Publication Status: 2-Awaiting Publication

Conference Name: SPIE 2017

Date Received: 08-Aug-2017 Conference Date: 07-Aug-2017

Date Published:

Conference Location: San Diego, CA

Paper Title: Real Phase Retrieval by orthogonal complements and hyperplanes

Authors: Sara Botelho-Andrade, Peter G. Casazza, Desai Cheng, John I. Haas, Tin T. Tran, Janet C. Tremain, Z

Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation

Publication Status: 2-Awaiting Publication

Conference Name: SPIE 2017

Date Received: 08-Aug-2017 Conference Date: 07-Aug-2017

Date Published:

Conference Location: San Diego, CA

Paper Title: Optimal projective packings from association schemes

Authors: Joseph W. Iverson, John Jasper, Dustin G. Mixon

Acknowledged Federal Support: **Y**

Nonlinear and Probabilistic Analysis with Frames

ARO Grant W911NF-16-1-0008

May 25th, 2017

Progress Report

UMD, College Park MD

Agenda

1:00pm –

- Introduction of participants
- Overview of activities & results (Radu): Papers, RIT, talks, visits, graduate students

1:15pm -

- Kasso Okoudjou:
 - Probabilistic Frames/HRT
 - Quantum Key Distributions
- Joey Iverson:
 - ETFs from Association Schemes & Zauner's Conjecture
- Rad Balu (ARL)
 - Applications of Frames to quantum key distribution and quantum graphs
- John Benedetto:
 - A generalization of Gleason's frame function in quantum mechanics
 - Super-resolution and Beurling's minimal extrapolation

3:15pm/3:30pm Break

3:30 pm

- Pete Casazza (University of Missouri):
 - Weighted Mean Square Error in Quantum Detection
 - Rank 2 projections in \mathbb{R}^{2n} from \mathbb{C}^n vectors

4:15pm –

- Radu Balan:
 - Optimal decompositions of positive semidefinite matrices ; Grothendieck inequality
 - Low Rank Matrix recovery; quantum state tomography; Lipschitz stability

4:45 pm –

- Wrap-Up

Summary of Activities

Senior Personnel

- UMD:
 - Radu Balan
 - John Benedetto
 - Wojtek Czaja
 - Kasso Okoudjou
- U. Missouri:
 - Pete Casazza
- ARL:
 - Rad Balu

Summary of Activities

Research

- Publications: 34 papers (18 accepted journal publications)
- Interactions:
 - RIT (Research Interaction Team): February 2016-present
 - Spring&Summer 2016: Quantum Information Systems
 - Fall 2016, Spring 2017: Applied Harmonic Analysis
 - Joint research projects:
 - John-Paul-Rad (Gleason's frame function)
 - Kasso – Paul – Rad (Quantum Key)
 - Joey – Rad (Quantum Markov Chain)
 - Desai-Pete-Kasso-Radu (July 2016 workshop at UMD)
- Dissemination:
 - Conference Talks: 21
 - Invited Talks: 20+

Summary of Activities

Mentoring

- Postdoctoral Associates:
 - UMD: Joey Iverson
- Selected list of graduate students:
 - UMD:
 - David Bekkerman
 - Addison Bohannon (also ARL)
 - Matt Guay (PhD 2016)
 - Naveed Haghani
 - U.Missouri:
 - Desai Cheng
- PIs have advised and graduated 6 PhD students during the past 18 months

Publications

Radu Balan (UMD)

- (1) R. Balan, D. Zou, *On Lipschitz Analysis and Lipschitz Synthesis for the Phase Retrieval Problem*, available online [arXiv:1506.02092](https://arxiv.org/abs/1506.02092) [math.FA], Linear Algebra and Applications 496, 152--181 (2016).
- (2) R. Balan, M. Begue, C. Clark, K. Okoudjou, *Optimization methods for frame conditioning and application to graph Laplacian scaling*, online [arXiv:1609.02233](https://arxiv.org/abs/1609.02233) [math.FA], to appear in "Novel methods in harmonic analysis with applications to numerical analysis and data processing", Lecture Notes ANHA Series, I. Pesenson and all Eds., Birkhauser 2017.
- (3) R. Balan, M. Singh, D. Zou, *Lipschitz Properties for Deep Convolutional Networks*, available online [arXiv:1701.05217](https://arxiv.org/abs/1701.05217) [cs.LG], submitted (2017).
- (4) R. Balan, K. Okoudjou, A. Poria, *On A Feichtinger Problem*, online arXiv:1705.06392 [math.CA] (2017).

Publications

John Benedetto (UMD)

- (1) J.J. Benedetto, A. Nava-Tudela, A. Powell, and Y. Wang, *A frame reconstruction algorithm with applications to MRI*, invited Chapter 9 in *Frames and Other, Bases in Abstract and Function Spaces: Novel Methods in Harmonic Analysis, Volume 1*, I. Pesenson, et al. editors, Springer-Birkhauser, New York, 2017, 28 pages.
- (2) J.J. Benedetto, M. Dellatorre, *Uncertainty principles and weighted norm inequalities*, invited Chapter in *Functional Analysis, Harmonic Analysis, and Image Processing: a Collection of Papers in Honor of Bjorn Jawerth, Michael Cwikel and Mario Milman*, editors, AMS Contemporary Mathematics, 2017, 24 pages
- (3) J.J. Benedetto, W. Li, *Super-resolution by means of Beurling minimal extrapolation*, submitted to *Applied and Computational Harmonic Analysis*, 2016.
- (4) J.J. Benedetto, T. Andrews and J. Donatelli, *Frame multiplication theory and vector-valued ambiguity functions*, to be submitted 2017, 45 pages
- (5) J.J. Benedetto, M. Dellomo, *Multiplicative frames and the theory and implementation of reactive sensing*, in preparation, 41 pages.
- (6) R. Balu, J.J. Benedetto, and P. Koprowski, *A generalization of Gleason's frame function in quantum mechanics*, preprint, 9 pages.

Publications

Pete Casazza (U.Missouri)

- (1) J. Cahill, P.G. Casazza, and I. Daubechies, *Phase retrieval in infinite dimensional Hilbert spaces*, Transactions of the AMS, Series B, 3 (2016) 63-76.
- (2) T. Bemrose, P.G. Casazza, D. Cheng, J. Haas, and H. Van Nguyen, *Computing the distance between frames and between subspaces of a Hilbert space*, Accepted by Contemporary Math.
- (3) T. Bemrose, P.G. Casazza, D. Cheng, J. Haas, and H. Van Nguyen, *Computing the distance between frames and between subspaces of a Hilbert space (The Complex Case)*, Submitted.
- (4) *I, Mathematician II - Further introspections on the mathematical life*, P.G. Casazza, S. Krantz, and R.D. Ruden, Eds., The Consortium for Mathematics and its Applications, Inc., Bedford, MA (2016).
- (5) Peter G. Casazza, Amineh Farzannia, John I. Haas, and Tin T. Tran, *Toward the Classification of Biangular Harmonic Frames*, Submitted ACHA. ArXiv 1610.03142. Accepted.
- (6) Sara Bothello-Andrade, Peter G. Casazza, Dorsa Ghoreishi, Shani Jose, Janet C. Tremain, *Weak phase retrieval and weak phaseless reconstruction*, arxiv: 1612.08018. Accepted.
- (7) Peter G. Casazza, Dorsa Ghoreishi, Shani Jose, Janet C. Tremain, *Norm retrieval and phase by projections*, Axioms, 6 (2017) 1-15. arxiv 1701.08014. Accepted.
- (8) P.G. Casazza and J. Haas, *On the structures of Grassmannian frames*, Proceedings of Sampta - Estonia (2017) 1-4.
- (9) P.G. Casazza and D. Cheng, *Associating vectors in C_n with rank 2 projections in \mathbb{R}^{2n} with applications*, Submitted to ACHA.
- (10) S. Bothello-Andrade, P.G. Casazza, D. Cheng, J. Haas, T. Tran, J.C. Tremain, Z. Xu, *Phase retrieval by hyperplanes*, arxiv: 1703.02657. accepted Contemporary Math.
- (11) J. Cahill, P.G. Casazza, J. Haas, and J.C. Tremain, *Constructions of biangular tight frames and their relationships with equiangular tight frames*, Submitted.

Publications

Wojciech Czaja (UMD)

- (1) J.J. Benedetto, W. Czaja, J. Dobrosotskaya, T. Doster, K. Duke, *Spatial-spectral operator theoretic methods for hyperspectral image classification*, GEM - International Journal on Geomathematics November 2016, Volume 7, Issue 2, pp 275-297.
- (2) W. Czaja, B. Manning, J.M. Murphy, K. Stubbs, *Discrete directional Gabor frames*, to appear in Applied and Computational Harmonic Analysis, 2017.
- (3) W. Czaja, T. Doster, and A. Halevy, *An Overview of Numerical Acceleration Techniques for Non-Linear Dimension Reduction*, to appear in Novel Methods in Harmonic Analysis, 2017.
- (4) W. Czaja and J. Emidih, *Heterogeneous Cancer Cell Line Data Fusion for Identifying Novel Response Determinants in Precision Medicine*, to appear in Proceedings of 13th International Symposium on Bioinformatics Research and Applications (ISBRA), 2017.
- (5) W. Czaja, W. Li, *Analysis of time-frequency scattering transforms*, submitted, 2016
- (6) W. Czaja and Y. Li, *Gabor Regression of Quantum Chemical Energies*, preprint, 2016

Publications

Joseph Iverson (UMD)

(1) J. Iverson, J. Jasper and D. Mixon, *Optimal Line Packings from Association Schemes*, submitted to Proc. London Math. Soc. - revision process.

Publications

Kasso Okoudjou (UMD)

- (1) M. Ionescu, K. A. Okoudjou, and L. G. Rogers, *Some spectral properties of pseudo-differential operators on the Sierpinski gasket*, Proc. Amer. Math. Soc., 145 (2017), no.5, 2183-2198.
- (2) R. Balan, M. Begue, C. Clark, and K. Okoudjou, *Optimization methods for frame conditioning and application to graph Laplacian scaling*, in "Novel methods in harmonic analysis with applications to numerical analysis and data processing", Lecture Notes ANHA Series, I. Pesenson and all Eds., Birkhauser 2017 (to appear).
- (3) C. Wickman and K. Okoudjou, *Duality and geodesics for probabilistic frames*, Linear Algebra Appl., (accepted), May 2017.
- (4) K. A. Okoudjou, *Extension and restriction principles for the HRT conjecture*, arXiv:1701.08129, submitted, January 2017.
- (5) M. Begue and K. A. Okoudjou, *Invertibility of graph translation and support of Laplacian Fiedler vectors*, arXiv:1703.05867, submitted, March 2017.
- (6) M. Bownik, M. S. Jakobsen, J. Lemvig, and K. A. Okoudjou, *On Wilson bases in $L^2(\mathbb{R}^d)$* , arXiv:1703.08600, submitted, March 2017.
- (7) D. Cheng and K. A. Okoudjou, *Optimal properties of the canonical tight probabilistic frame*, arXiv:1705.03437, submitted, May 2017.

Conference Talks

John Benedetto:

- (1) Invited short talk at AMS special session on Frames and Sampling at JMM Atlanta 2017-01.
- (2) Invited short talk at AMS special session on Signal Processing at JMM Atlanta 2017-01.
- (3,4) One plenary and one colloquium at CIMPA, Buenos Aires, July 2017.

Wojciech Czaja:

- (1) Invited talk at Time-Frequency Analysis and Related Topics Conference, Strobl, Austria, June 9, 2016.
- (2) Invited talk at DTRA Basic Research Technical Review, Springfield, VA, July 18, 2016.
- (3) Invited talk at SIAM Conference on Computational Science and Engineering, Atlanta GA, February 27, 2017.

Kasso Okoudjou:

- (1) QCrypt 2016 Conference (joint with Rad & Paul)
- (2) AMS Special Session on Frame Theory, College of Charleston, March 2017.
- (3) AMS Special Session on Bases in Function Spaces: Sampling, Interpolation, Expansions and Approximations, JMM, Atlanta, January 2017.

Conference Talks

Radu Balan:

- (1) Workshop on "Harmonic Analysis, Graphs, and Learning", Bonn, Germany, March 2016.
- (2) AMS Sectional Meeting on Frames, Wavelets, and Gabor Systems, North Dakota State University, Fargo, ND, April 2016.
- (3) Invited short talk at AMS special session on Frames and Sampling at JMM Atlanta 2017-01.
- (4) Invited short talk at AMS special session on Signal Processing at JMM Atlanta 2017-01.

Joseph Iverson:

- (1) AMS Spring Eastern Sectional Meeting, Special Session on Bases in Hilbert Function Spaces, May 2017.
- (2) AMS Spring Southeastern Sectional Meeting. Special Session on Frame Theory, March 2017.

Pete Casazza:

- (1) AMS Sectional Meeting on Frames, Wavelets, and Gabor Systems, North Dakota State University, Fargo, ND, April 2016.
- (2) AMS Sectional Meetings on Topological Phases of Matter and Quantum Computation, Bowdoin College, Brunswick, ME, September 2016.
- (3) Talk in special session Applied Harmonic Analysis and frame theory at the biannual IWATA, Wash.U., St. Louis, MO, July 2016.
- (4) BIRS Mexico, Oct. 2016.
- (5) Invited short talk at AMS special session on Frames and Sampling at JMM Atlanta 2017-01.